

Signal vs. Noise: Obtaining a representative $\delta^{18}\text{O}$ record in a low-accumulation region

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1 A 2D view of Antarctic $\delta^{18}\text{O}$

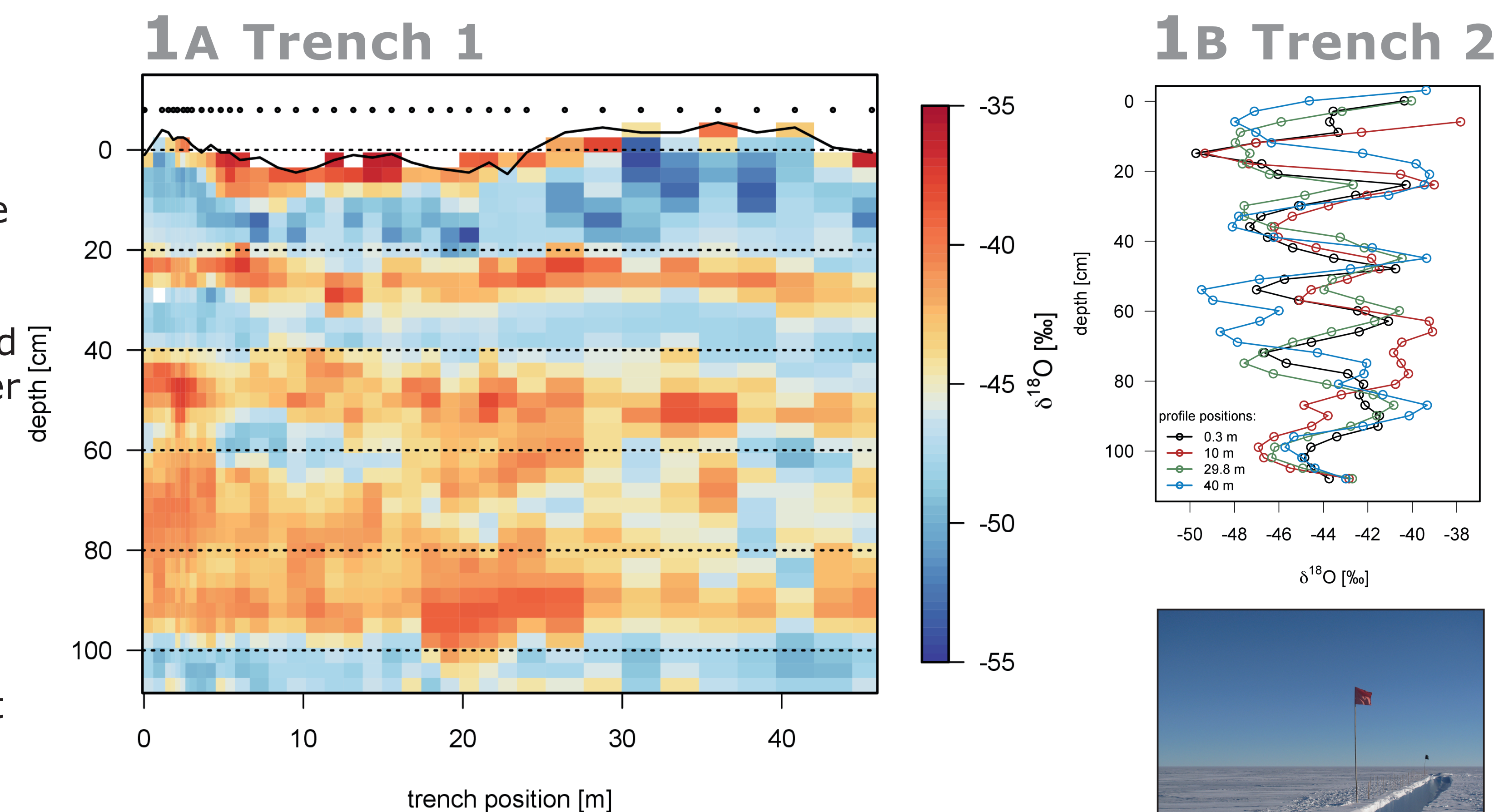
Single ice cores from low-accumulation regions in Antarctica may not be representative recorders of the Holocene climate evolution (Karlöf et al., 2006). Similarly, Gfeller et al. (2014) found ionic aerosol proxies from a single firn core at the Greenland NEEM site recording only 30 % of the inter-annual atmospheric variability.

Both findings show that the climate signal in firn cores is obscured by noise processes on different spatial and temporal scales (Fisher et al., 1985; Persson et al. 2011; Johnsen et al., 2000).

We aim at a better understanding of noise in firn cores to allow a reliable estimate of the climate signal recorded.

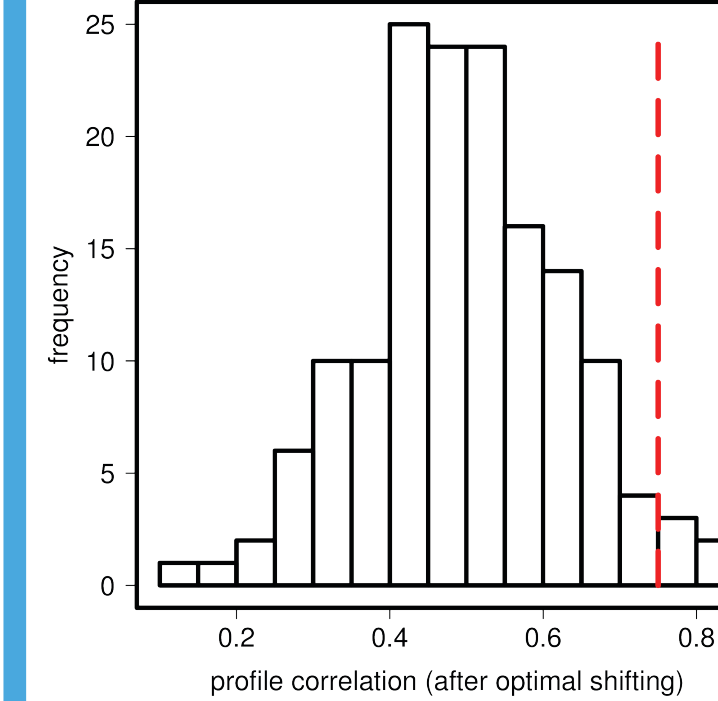
The trench approach (Fig. 1):

- 2 firn trenches of **45 m length** x **1.2 m depth**; excavated at Kohnen station, Dronning Maud Land (see picture to the right)
- **spatial separation 500 m**
- isotopic sampling of **38**, respectively **4**, profiles



2 A representative firn record

2A

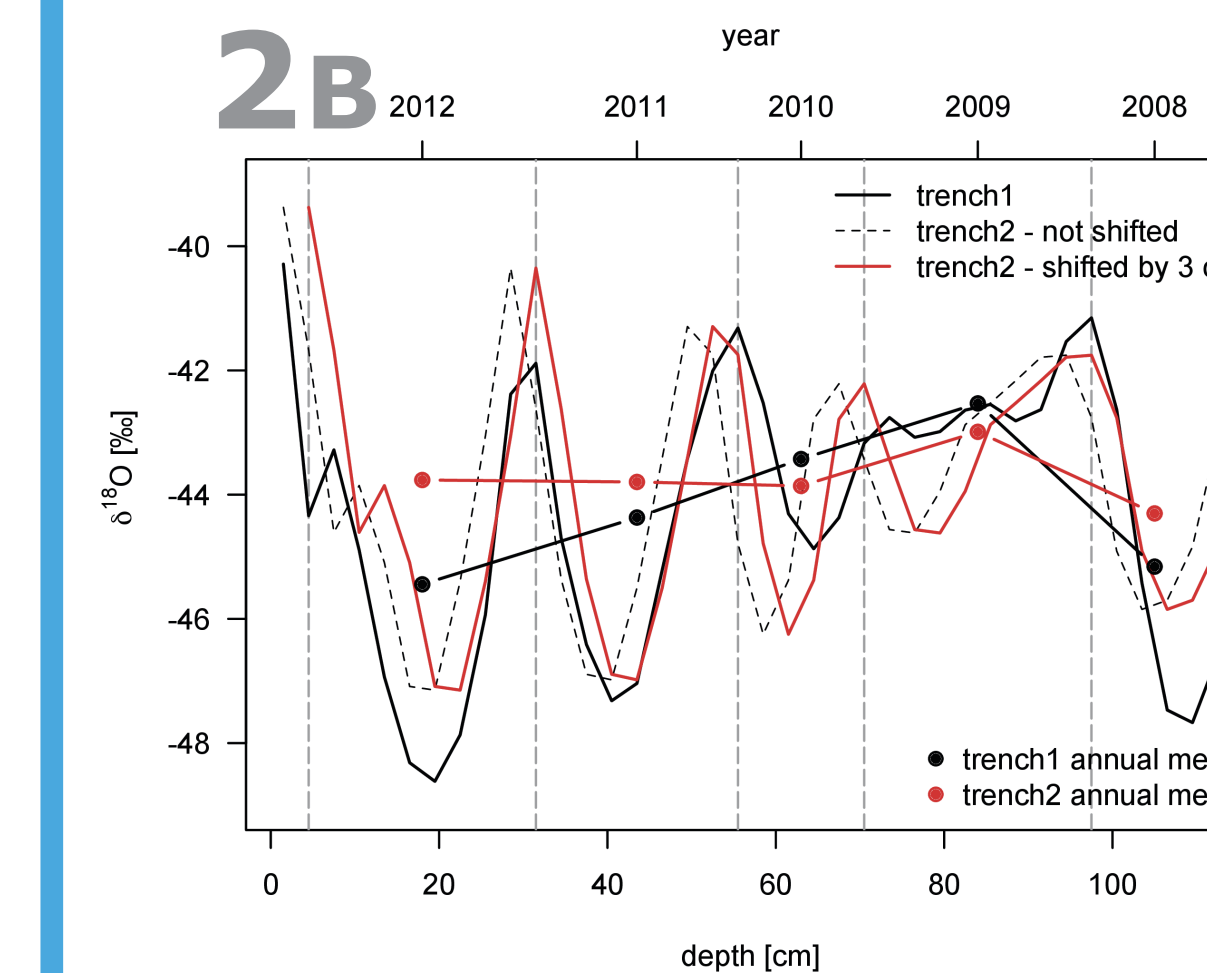


Single isotope profiles of trench 1 show a broad distribution of correlations with the single profiles obtained from trench 2 (Fig. 2A).

To obtain a representative isotopic signal for our study site, the spatial mean of all single isotopic profiles

from the two firn trenches is calculated (Fig. 2B). The 38 trench 1 profiles are spaced between 0.1 and 2.5 m, the 4 trench 2 profiles at 10-20 m.

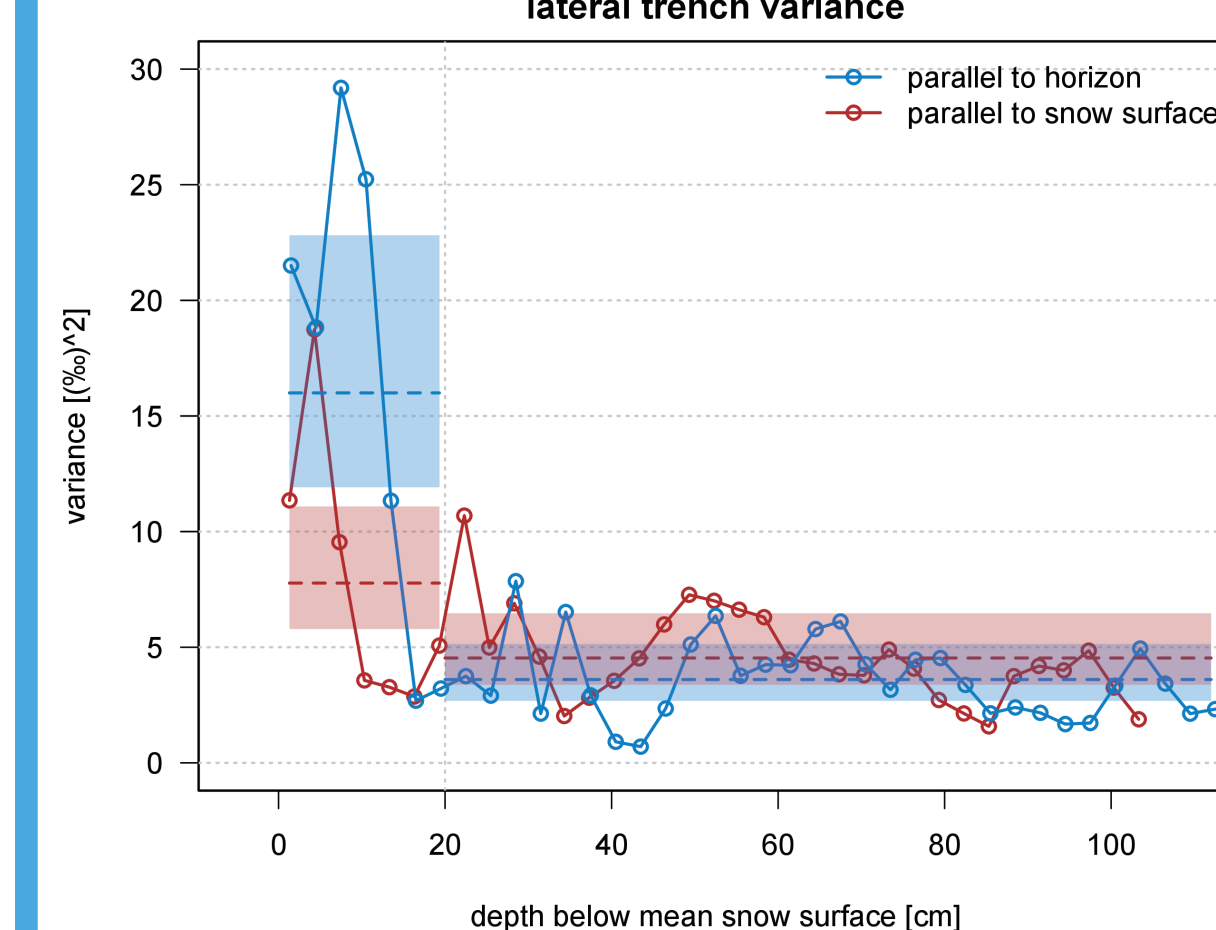
The mean profiles are well correlated ($R=0.75$), indicating a common climatic signal over a



spatial scale of 500 m. However, still significant profile deviations are found.

3 A model for stratigraphic noise

3A



The signal and noise content of the trench record is expressed by the **down-core variance**, the **lateral variance** (Fig. 3A) and the **spatial covariance** of the variability.

A simple model of the stratigraphic noise structure (the spatial covariance) is given by an **AR(1) autoregressive process**, as suggested by the isotopic seasonal layering and the inter-profile correlation (Fig. 3B):

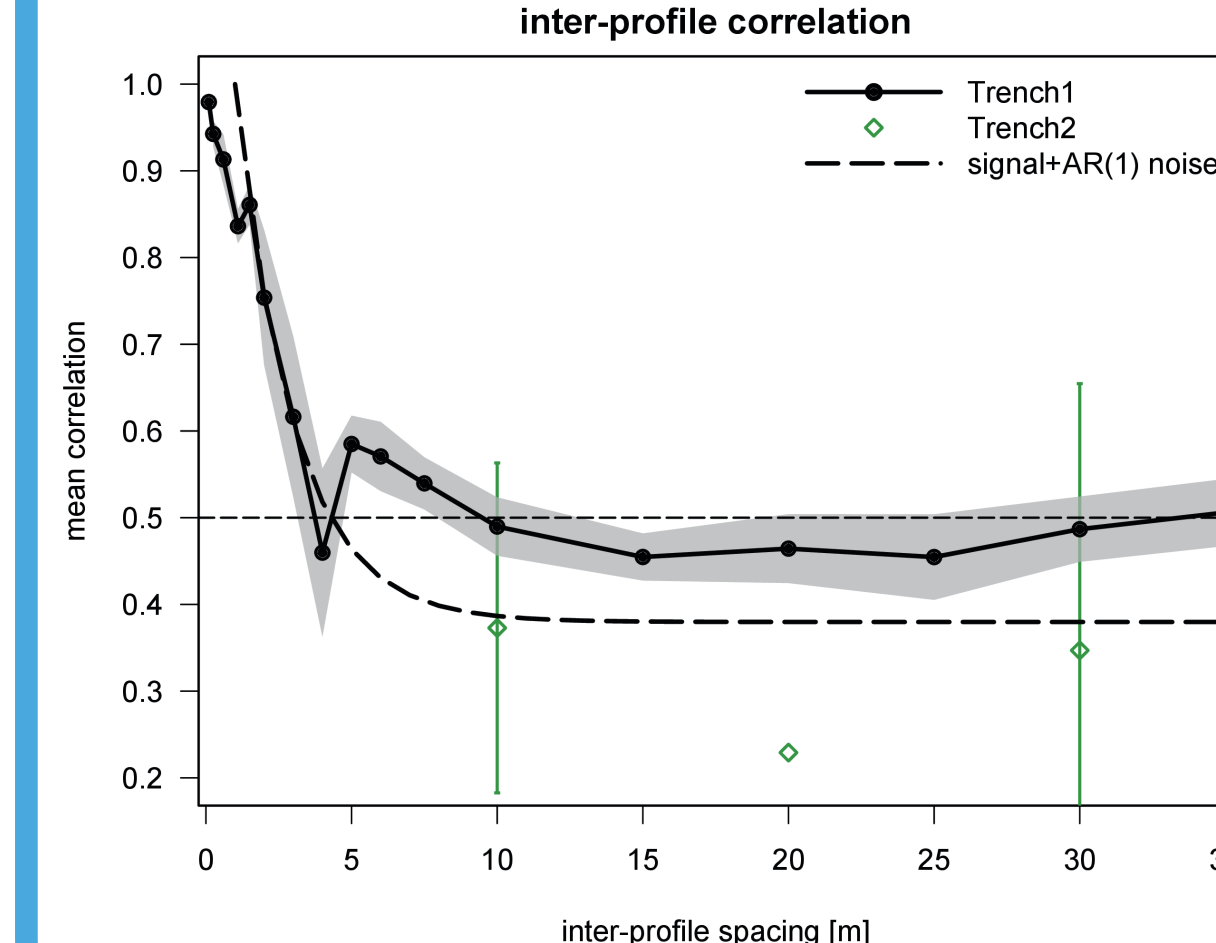
$$X_n(t) = s(t) + a\varepsilon_{n-1}(t) + \sqrt{1-a^2}\varepsilon_n(t) \quad (1)$$

Assuming independence of signal and noise, the inter-profile correlation as well as the correlation between two sets of profile averages can then be given analytically

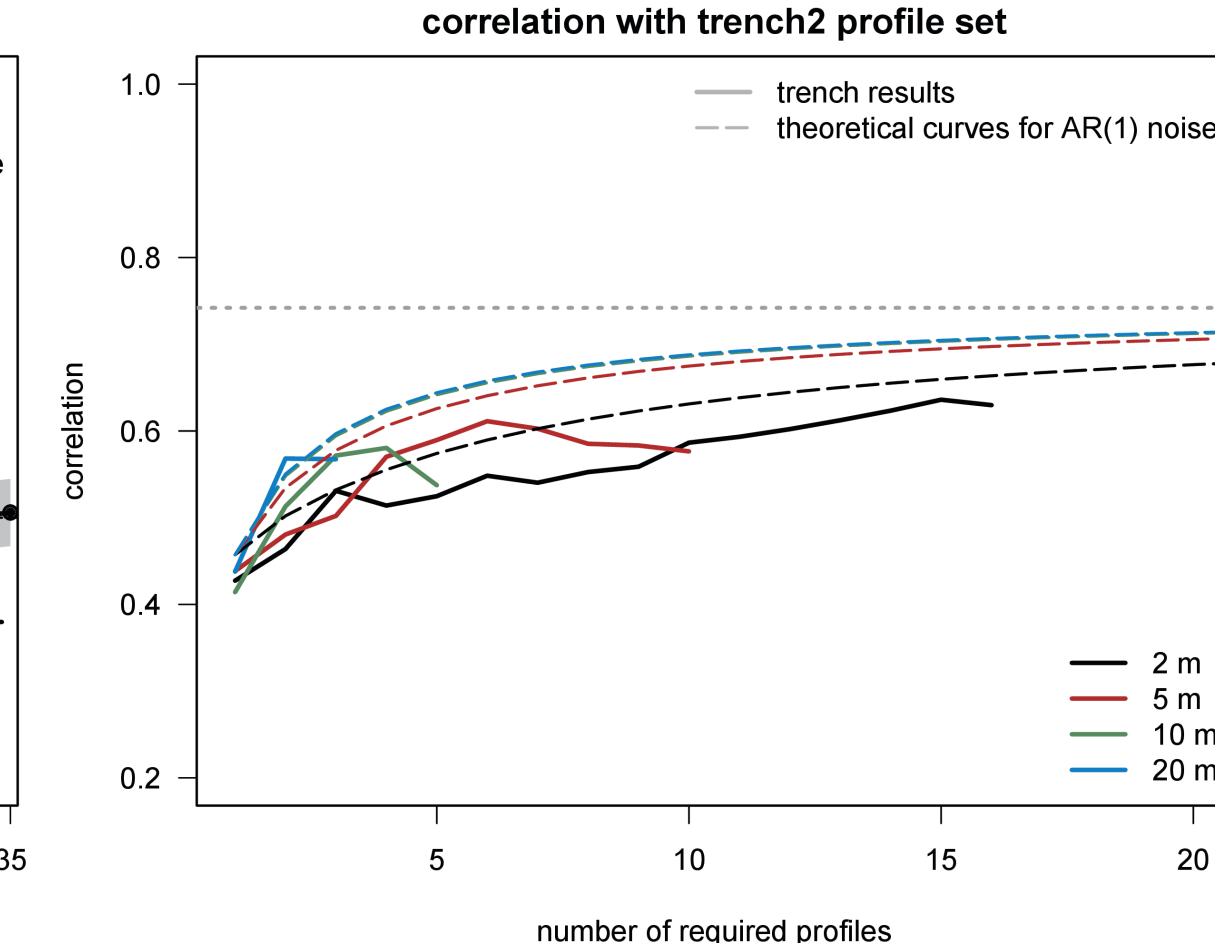
for AR(1) noise:

$$r_{XY} = \frac{\text{var}(S) + a^{|x-y|/\Delta l} \text{var}(\varepsilon)}{\text{var}(S) + \text{var}(\varepsilon)} \quad (2) \quad r_{\bar{X}\bar{Y}} \approx \left\{ \left(1 + \frac{\text{var}(\varepsilon)}{\text{var}(S)} \frac{\sigma_X^{*2}}{N_X^2} \right) \left(1 + \frac{\text{var}(\varepsilon)}{\text{var}(S)} \frac{\sigma_Y^{*2}}{N_Y^2} \right) \right\}^{-1/2}, \quad \sigma^{*2} = \sigma^2(N, a) \quad (3)$$

3B



3C



Parameters of the model:

- the noise variance $\text{var}(\varepsilon)$; given by the lateral trench variance (Fig. 3A, mean = $5.9 (\text{‰})^2$)
- the signal variance $\text{var}(S)$; given by the down-core variance (mean = $9.5 (\text{‰})^2$) reduced by the noise variance
- the autocorrelation parameter a ; estimated from the autocorrelation function of the lateral variance with $a = 2 \text{ m}$

4 Implications

The correlation of single profiles in trench 1 (Fig. 3B) as well as that between the trenches (Fig. 3C) is well captured by our AR(1) model of the stratigraphic noise. Thus, noise on the snow dune scale is the main noise process over spatial scales of at least 500 m.

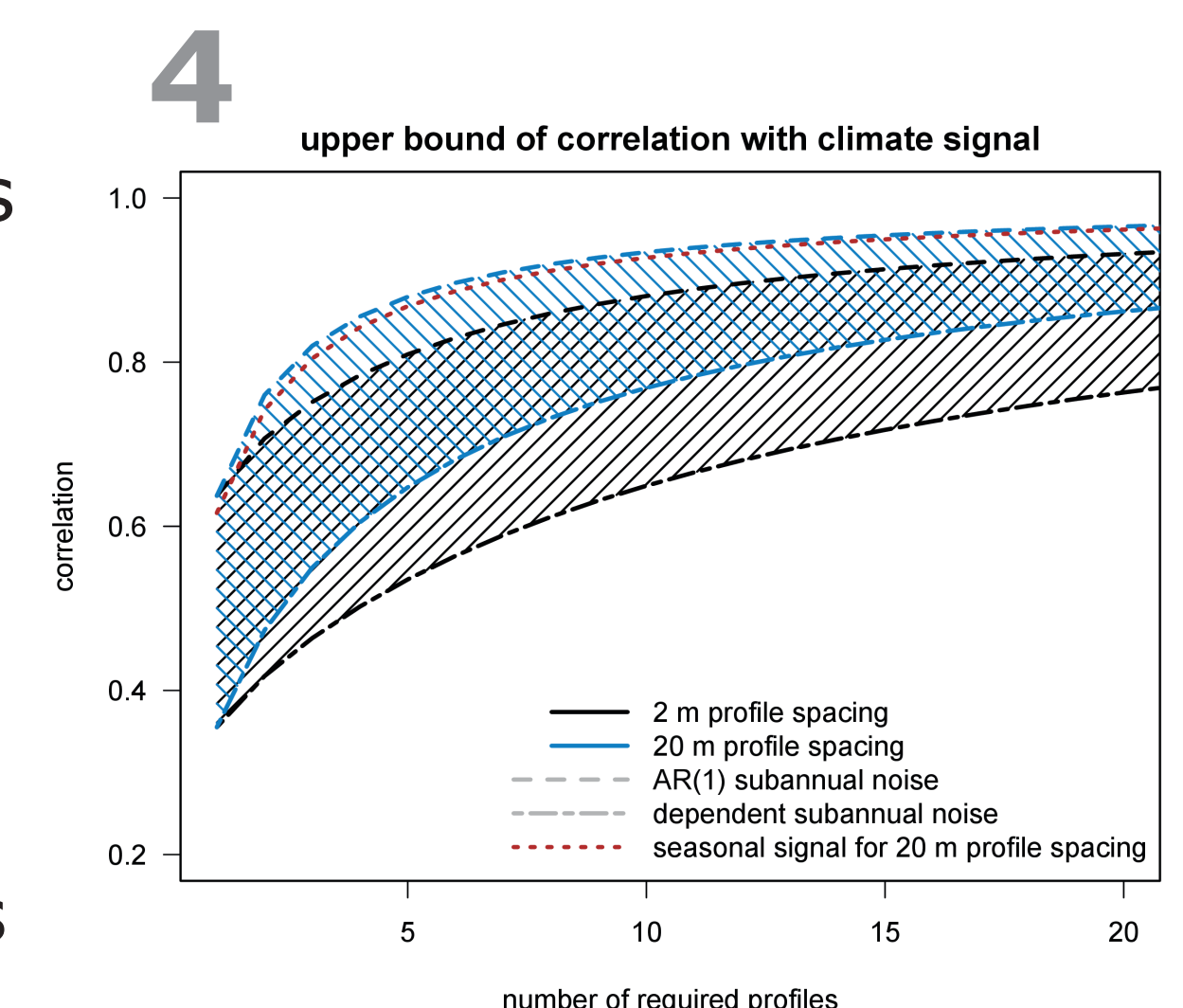
Letting $N_Y \rightarrow \infty$ in Eq. (3) yields the correlation with a hypothesised true climate signal (red dotted line in Fig. 4).

For annual $\delta^{18}\text{O}$ time series, the vertical noise structure has to be known. Due to the limited vertical extent of the trench record, it can only be approximated. In the best case, we assume the vertical noise to be also following an AR(1) process (dashed lines, Fig. 4), in the worst case we assume a complete dependence on the subannual time scale (dash-dotted lines, Fig. 4).

Our results show:

Representativity of seasonal and annual $\delta^{18}\text{O}$ time series from single low-accumulation firn cores is low due to stratigraphic noise on the snow dune scale.

Correlation with the climate signal is strongly increased by taking a sufficient number of cores with an optimal sampling strategy.



References

Fisher et al., *Ann. Glac.*, **7**, 1985.
Gfeller et al., *The Cryosphere*, **8**, 2014.
Karlöf et al., *JGR*, **111**, 2006

Johnsen et al., in: *Physics of Ice Core Records*, **159**, 2000
Persson et al., *JGR*, **116**, 2011.